ESTUARY LESSON PLAN

Getting Physical with Estuaries

Focus

Physical Factors in Estuary Environments

Grade Level

9-12

Focus Question

How do physical factors in estuaries vary over time, and how do variations in one factor affect other factors?

Learning Objectives

- Students will identify and quantify variations in selected physical factors in estuary environments.
- Students will explain the relationships between water depth, salinity, temperature, and dissolved oxygen, and how variations in one of these factors can affect the others.
- Given a series of observations on water depth, salinity, temperature, and dissolved oxygen in an estuary, students will make inferences about relationships and processes that explain these observations.

Materials Needed

- copies of "NERRS System-wide Monitoring Program Database Worksheet," one copy for each student group
- (optional) Computers with internet access; if students do not have access to the internet, download copies of materials cited under "Learning Procedure" and provide copies of these materials to each student or student group
- a spreadsheet program such as Microsoft Excel®

Audio/Visual Materials Needed

None

Teaching Time

One or two 45-minute class periods, plus time for student research

Seating Arrangement

Groups of 3 - 4 students

Maximum Number of Students

30

Key Words

Estuary
Salinity
Dissolved oxygen
Temperature
Physical factors
National Estuary Research Reserve System

Background

Estuaries are bodies of water and adjacent wetlands found in areas where rivers flow into much larger bodies of water. Most estuaries are formed when a river meets the sea, and the water in these estuaries is a mixture of freshwater and saltwater from the ocean. But there are also freshwater estuaries that occur where rivers flow into much larger bodies of freshwater such as the Great Lakes.

Estuaries are some of the most biologically productive systems on Earth and provide food, recreation, and economic opportunities to human communities, as well as habitats, food, and protected breeding areas for many species. Because of these benefits, many human communities are located in or near estuaries; and as a result, many estuaries have been damaged by human activities such as dredging, inappropriate industrial activity, and poor agricultural practices. In addition, estuaries are exposed to a variety of natural disturbances including winds, waves, heavy rainfall, and severe storms.

Threats to estuaries coupled with their importance led to the establishment of the National Estuarine Research Reserve System (NERRS). NERRS protects more than one million acres in 26 estuaries that represent a range of coastal estuarine

habitats in the United States and its territories. In addition to protecting representative sites, NERRS conducts research to investigate the effects of natural processes and human activities on estuaries. A key part of this research is the System-wide Monitoring Program (SWMP; pronounced "swamp"), which includes regular measurements of water quality indicators (water temperature, specific conductivity, salinity, dissolved oxygen, depth, pH, and turbidity); meteorological data (air temperature, relative humidity, barometric pressure, wind speed, wind direction, precipitation, and solar radiation); and nutrient data (orthophosphate, ammonium, nitrite, nitrate, nitrite+nitrate and chlorophyll).

This lesson is intended to introduce students to information available from the NERRS SWMP and to simple techniques for analyzing these data to investigate environmental conditions in specific estuaries.

Learning Procedure

1.

Preparation: Visit the NERRS Centralized Data Management Office Web site at *http://cdmo.baruch.sc.edu/*. You may want to follow some or all of the directions in the "NERRS System-wide Monitoring Program Data Base Worksheet" to become familiar with these procedures and the types of information available at this site. If your students will be using a spreadsheet program other than Microsoft Excel® you may need to modify the directions for setting up the spreadsheet and preparing graphs of the data.

2.

Direct students to the Estuaries Tutorial at *http://oceanservice.noaa.gov/education/kits/estuaries*. You may want to assign different tutorial sections to individual students within each student group. Have each student or student group complete one version of the Self-Test, and lead a discussion to review the answers.

3.

You may need to review some of the following concepts before students begin working with the SWMP Database:

- Salinity is defined as the content of dissolved salts in

seawater. Since seawater contains a variety of salts (magnesium sulfate, magnesium chloride, calcium carbonate, etc.) in addition to sodium chloride, salinity is not directly equivalent to the concentration of sodium chloride in seawater. Salinity is measured in parts per thousand (ppt or ‰), which is equivalent to grams per kilogram. Freshwater has a salinity of 0 ‰; normal seawater has a salinity of about 35 ‰.

- Specific Conductivity is a measure of a material's ability to conduct an electric charge. In water, conductivity is related to salt content and is used to estimate salinity. The units of conductivity are siemens per centimeter (S/cm). Since 1S/cm is a very high level of conductivity for most solutions, conductivity is usually expressed in millisiemens per centimeter (mS/cm). One millisiemen is one-thousandth of a siemen. The specific conductivity of "fresh" water ranges from 0.001 to about 1.000 mS/cm. The specific conductivity of seawater is about 55 mS/cm.

  [Conductivity is the opposite of resistance. The unit of resistance measurements is the ohm, which is the resistance of an electrical circuit in which a voltage of one volt produces a current of one ampere. Conductivity is defined as the reciprocal of resistance and its unit formerly was the mho (ohm spelled backward). Most scientists now use the siemen as the unit of conductivity, but it is equivalent to the mho. Because conductivity of a solution depends upon the distance between the electrodes of the measuring instrument, conductivity is given in siemens per centimeter (S/cm) or millisiemens per centimeter (mS/cm).]

- Units for dissolved oxygen measurements are usually milligrams per liter or parts per million (ppm; equivalent to mg/kg). Solubility of oxygen (the amount of oxygen that will dissolve in water) depends upon temperature, salinity, and other factors. For this reason, dissolved oxygen may also be expressed as a percentage of saturation, which compares the level of dissolved oxygen in a water sample with the maximum amount of dissolved oxygen that could be contained in water having the same temperature, salinity, etc., as the sample.

Solubility of oxygen decreases as salinity and temperature increase. Cold freshwater may have dissolved oxygen concentrations around 17 ppm, while the concentration of dissolved oxygen in cold seawater is around 10 ppm. Dissolved oxygen concentrations less than 5 ppm are generally considered to be low and are particularly harmful to aquatic organisms during summer months when metabolic rates are high.

- Turbidity is a measurement of the amount of suspended matter in a water sample. Because suspended matter causes light to scatter as it passes through a water sample, turbidity is often estimated with an instrument called a nephelometer, which measures the amount of light that is absorbed and scattered by a water sample. The units for turbidity measured this way are called nephelometric turbidity units (NTU). A clear stream might have a turbidity of 1 NTU, while the turbidity of a large river might be around 10 NTUs during dry weather and several hundred NTUs after heavy rainfall because of runoff.

4.

Distribute copies of the "NERRS System-wide Monitoring Program Database Worksheet" to each student group. Tell students that their assignment is to use the NERRS SWMP Database to answer the questions on the worksheet.

5.

Have each student group present their charts and lead a discussion of students' answers to the worksheet questions.

Students should recognize a regular oscillation in water depth and infer that this is due to tidal motion within the estuary. The twice daily cycles are particularly evident in the charts for a single day's worth of data. Salinity levels correlate most strongly with water depth variations, and this is particularly striking in data from January 15, 2003. Higher salinity levels correlate with higher water levels, and students should infer that this is due to the influx of seawater. Oscillations in dissolved oxygen and temperature levels also resemble water depth variations, particularly in the latter half of the November 8 - 18, 2002, period. Since peaks in temperature coincide with

higher water levels during this period, students may infer that seawater was warmer than inflowing freshwater at this time. Peaks in dissolved oxygen show a similar correlation, suggesting that ocean waters may have been more aerated than freshwaters, perhaps as a result of wave action.

Dissolved oxygen levels are highest during colder months, and lowest during the hottest months. This obviously suggests a relationship between dissolved oxygen and temperature, and students should realize that the capacity of water for dissolved gases is reduced as water temperature increases. Encourage students to speculate on other processes that could contribute to the observed relationship. You may want to remind them that metabolic processes in living organisms are generally more active during warmer months and that oxygen consumption of aerobic organisms increases with increasing metabolic activity; so dissolved oxygen might be depleted by an increase in metabolic activity associated with increased temperature. Higher temperatures may also encourage the rapid growth of aquatic plants. When these plants die, decomposition of large masses of decaying vegetation consumes oxygen and lowers the level of dissolved oxygen.

Students should recognize that salinity levels dropped during the latter portion of the November 8 - 18, 2002, period following heavy precipitation a day or so earlier. Oscillations in dissolved oxygen levels also became more pronounced at the same time, suggesting that the influx of freshwater from heavy rains resulted in increased oxygen consumption perhaps because the resulting runoff carried additional organic matter into the estuary. Metabolism of this organic matter could results in increased oxygen consumption and consequently lower levels of dissolved oxygen.

Students should identify the following maximum daily and annual ranges:

- Temperature - about 3° C (April 15, 2003); annual range about 19° C
- Salinity - about 7 ‰ (January 15, 2003); annual range about 19 ‰
- Dissolved oxygen - about 2 mg/L (July 15, 2003); annual range about 7 mg/L

The Bridge Connection

www.vims.edu/bridge/ – Click on "Ocean Science Topics" in the navigation menu to the left, then "Habitats," then "Estuary."

The "Me" Connection

Have students write a brief essay describing three things that they could personally do to help protect and enhance one or more estuaries, and how these actions would be personally important.

Extensions

Have students select other estuaries included in the NERRS and prepare brief reports about these systems, including information on variations in environmental factors based on information in the SWMP Database.

Resources

http://cdmo.baruch.sc.edu/ – National Estuarine Research Reserve System Centralized Data Management Office website

http://www.epa.gov/owow/estuaries/kids/ – Games and activities about estuaries produced through the National Estuary Program

http://www.onr.navy.mil/focus/ocean/ – Oceanography site from the Office of Naval Research including online quizzes and activities. See the "Habitats" section for information and activities about estuaries.

http://www.ncnerr.org/education/estnet/index.html – "Estuary-Net Project;" an online project for grades 9-12 to help solve non-point source pollution problems in estuaries and their watersheds

National Science Education Standards

Content Standard A: Science as Inquiry

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standard C: Life Science

- Interdependence of organisms
- Matter, energy, and organization in living systems

Content Standard D: Earth and Space Science

- Geochemical cycles

Content Standard F: Science in Personal and Social Perspectives

- Natural resources
- Environmental quality
- Natural and human-induced hazards

ESTUARY REVIEW

NERRS System-wide Monitoring Program Database Worksheet

Long-term environmental monitoring is a key activity of NOAA's National Estuarine Research Reserve System (NERRS). The NERRS System-wide Monitoring Program (SWMP; pronounced "swamp") includes regular measurements of water quality indicators, meteorological data and nutrient data. Water quality indicators include water temperature, specific conductivity, salinity, dissolved oxygen, depth, pH, and turbidity.

Meteorological data include air temperature, relative humidity, barometric pressure, wind speed, wind direction, precipitation, and solar radiation. Nutrient data include orthophosphate, ammonium, nitrite, nitrate, nitrite+nitrate and chlorophyll. The NERRS Centralized Data Management Office (CDMO) provides technical support to monitoring programs in each of the 26 NERRS estuaries, and also provides access to data from these programs to researchers and anyone else who is interested in this information.

Your assignment is to retrieve data from the CDMO database for a specific estuary and analyze these data to make inferences about some of the processes that affect environmental conditions in this estuary.

The easiest way to do this analysis is to import the data into a spreadsheet program that will allow you to sort, summarize, and graph them. Here's how to retrieve SWMP data and import them into Microsoft Excel® using the ACE Basin estuary as an example:

1. Open the CDMO Data Dissemination page at *http://cdmo.baruch.sc.edu/graphing_tool.html*. Click the "Yes" button, then scroll down and click on "Ashepoo Combahee Edisto (ACE) Basin, South Carolina" under "Water Quality Data."

2. Click on the "Data" link under "Mosquito Creek • 2002." You will see a table that includes ten columns containing

the following data (note that data entries are blank until October 15, 2002, at 11:30:00):
Column 1: Date (month, day, year)
Column 2: Time (24-hour system; hour, minute, seconds; notice that data are recorded every 30 minutes)
Column 3: Temperature (°C)
Column 4: Specific Conductivity (mS/cm)
Column 5: Salinity (parts per thousand)
Column 6: Dissolved Oxygen (percent of saturation)
Column 7: Dissolved Oxygen (mg/L)
Column 8: Depth (m)
Column 9: pH
Column 10: Turbidity (National Turbidity Units)

3. Highlight the data entries from 11/08/2002, 00:00:00, through 11/18/2002, 23:30:00 . Copy these data, then paste them into Microsoft Excel® by clicking in cell A1, then selecting "Paste" under the "Edit" pulldown menu. You should now have a spreadsheet containing ten columns (A through J) and 528 rows.

5. Click on the cell labeled "1" in the upper left corner of the spreadsheet, and choose "Rows" under the "Insert" menu. Label each column as follows:
Column 1: Date
Column 2: Time
Column 3: Temp
Column 4: SpCond
Column 5: Sal
Column 6: DO %
Column 7: DO mg/L
Column 8: Depth
Column 9: pH
Column 10: Turb

6. Prepare data summary graphs for temperature, salinity, dissolved oxygen (mg/L), and depth as follows:
a. Highlight all cells in columns C, E, G, and H for temperature, salinity, dissolved oxygen (mg/L), and depth, respectively.
b. Click on the Chart Wizard icon. Select "Line" under "Chart type" and the upper left icon under "Chart sub-

type." Click "Next."

c. Be sure the button next to "Columns" is selected under "Series in." Click "Next."

d. Click the "Titles" tab. Enter a title for your chart. Enter "Sample Interval (30 minutes)" in the "Category (X) axis" box and "Temp (°C), Sal (ppt), DO (ppt), Depth (m)" in the "Value (Y) axis" box. Click "Next."

e. Click the button next to "As new sheet" and enter "Temp, Sal, DO, Depth". Click "Finish." You now have a chart that shows variations in temperature, salinity, dissolved oxygen, and depth at the Mosquito Creek monitoring station during November 8 – 18, 2002.

f. If you want to print your chart and do not have a color printer, you may want to modify the line patterns and background. To do this, double click on the background area of your chart. The "Format Chart Area" dialogue box will open. Click the "None" button under "Area." Click "OK." Now click on one of the plotted lines on your chart. The "Format Data Series" dialogue box will open. Click on the "Patterns" tab, then the "Custom" button under "Line." Select the solid line or one of the three patterned lines in the window next to "Style," and select-black in the window next to "Color." You may also want to select a heavier line in the window next to "Weight." Click "OK." Repeat these steps for the other lines on your chart.

7. Return to the ACE Basin Water Quality Data page (*http://cdmo.baruch.sc.edu/ace.html*). Click on the "Link to ACE NERR Meteorological Data here" link at the bottom of the page. Under "Bennett's Point • 2002," click the "Hourly totals" link under "Precipitation Data." You will see a table that includes seven columns containing the following data:
Column 1: An identification number for the sampling station
Column 2: Julian day (1 for Jan. 1, 365 for Dec. 31, etc.)
Column 3: Month
Column 4: Calendar Day
Column 5: Year
Column 6: Time
Column 7: Precipitation (mm) recorded at intervals of one hour
Highlight the data entries for November 8 through

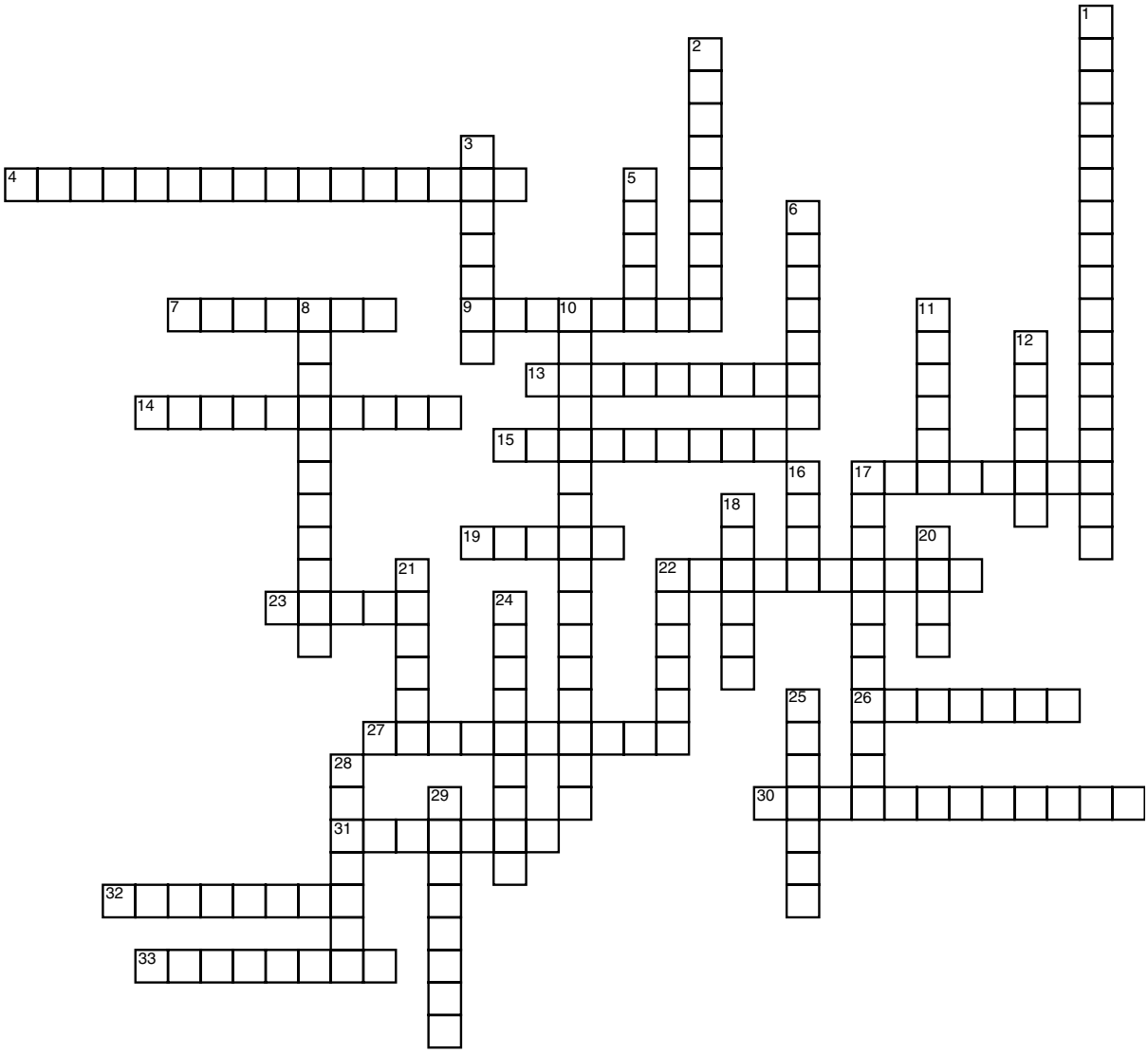
November 18. Copy these data, then paste them into a word processing program. Prepare a chart of these data as directed in steps 3 through 6, except use column labels described above, and only highlight column G (Precipitation) in step 6a. Notice that since these data are recorded at intervals of one hour, there are only half as many data points (264) as for the water quality data.

8. Repeat steps 3 through 7 to prepare summaries of water quality data from Mosquito Creek for January 15, 2003; April 15, 2003; July 15, 2003; and October 15, 2003. Notice that two columns have been added to the 2003 data. Be sure to highlight the columns for temperature, salinity, dissolved oxygen (mg/L), and depth when constructing your charts.

9. Use your charts for clues to the following questions:
   a. What pattern do you see in variations in water depth? What do you think causes these variations?
   b. What other factors (temperature, salinity, and/or dissolved oxygen) seem to have variations that coincide with variations in water depth? Why do they coincide?
   c. How do the overall values of dissolved oxygen vary at different times of the year? Does there seem to be a relationship between dissolved oxygen levels and temperature, salinity, and/or water depth?
   d. Are there any indications that precipitation affected water depth, temperature, salinity, and/or dissolved oxygen between November 8 - 18, 2002? If so, how do you explain the observed effects?
   e. Organisms living in estuaries are subjected to long- and short-term variations in temperature, salinity, dissolved oxygen, and other important environmental conditions. Based on your charts for January 15, April 15, July 15, and October 15, 2003, what is the maximum daily range of temperature, salinity, and dissolved oxygen experienced by estuarine organisms living in Mosquito Creek? What is the annual range of these factors?

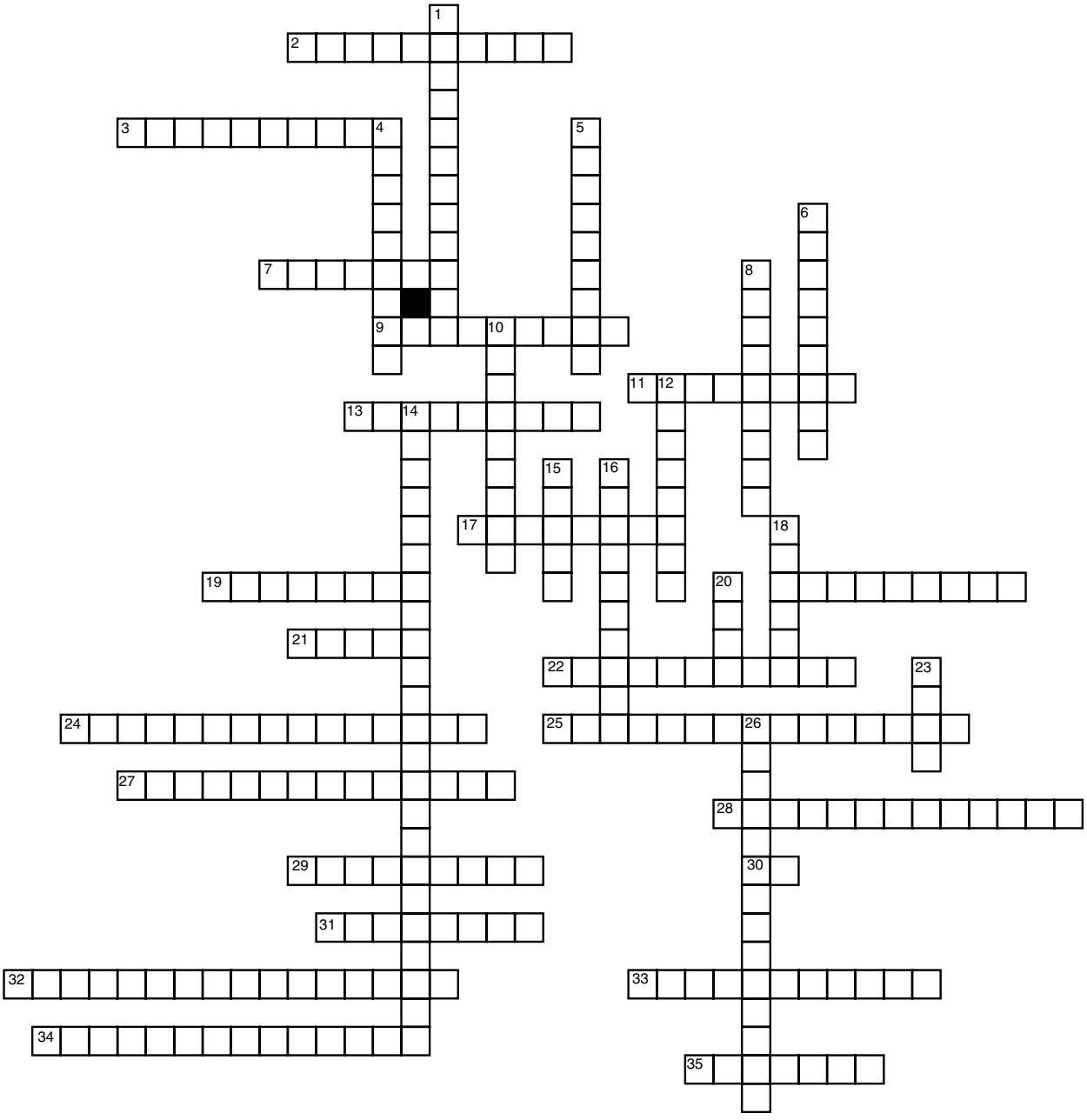
ESTUARY SELF TEST

Crossword Puzzle No. 1



ESTUARY SELF TEST

Crossword Puzzle No. 2



Crossword Puzzle 1:

Across

4. A _____ estuary occurs when river flow is low and tidally generated currents are moderate to strong. [two words]
7. Estuaries and their surrounding wetlands act as _____ that stabilize shorelines and protect coastal areas from floods, storm surges, and excessive erosion.
9. Estuaries with a sill are found in areas that were once covered with _____.
13. _____ estuaries occur when a rapidly-flowing river discharges into the ocean where tidal currents are weak. [two words]
14. Estuaries filter out _____ from rivers and streams before they flow into the oceans
15. One reason that estuaries are so productive is that the water filtering through them brings in _____ from the surrounding watershed.
17. _____ estuaries are formed when the earth's tectonic plates run into or fold-up underneath each other
19. _____ are a major influence on many estuaries.
22. Estuaries formed by rivers or streams entering massive lakes are called _____ estuaries.
23. A _____ is characterized by large flat fan-shaped deposits of sediment at the mouth of a river.
26. An _____ is a partially enclosed body of water and its adjancent habitats where saltwater from the ocean mixes with freshwater from rivers or streams.
27. _____ are areas in water that have equal salt concentrations.
30. _____ estuaries are formed when rising sea levels flood existing river valleys. [two words]
31. _____ beaches and islands are formed by the accumulation of sand or sediments deposited by ocean waves.
32. _____ estuaries are characterized by barrier beaches or islands that form parallel to the coastline and separate the estuary from the ocean. [two words]
33. In the ocean the concentration of salts, or _____, averages about 35 parts per thousand

Down

1. _____ are fundamental life support processes upon which all organisms depend. [two words]

2. Estuaries are often called _____ of the sea.
3. Estuaries are typically classified based on how saltwater and freshwater mix in the estuary and on their _____.
5. Because freshwater flowing into the estuary is less _____ than water from the ocean, it often floats on top of the heavier seawater.
6. Tides at broad mudflats might appear to be _____ than tides at the end of a long, narrow inlet.
8. The first stage in the formation of a tectonic estuary typically occurs during _____.
10. The _____ determines the rate of freshwater that flows into an estuary from rivers and streams. [two words]
11. When a sill prevents deep waters in an estuary from mixing with deep waters of the sea, poor water exchange causes _____ (low oxygen) water to build up on the bottom of the estuary.
12. The shape of the isohalines indicates the amount of _____ that is occurring, and may provide clues about the estuary's geology.
16. Estuaries provide habitat for more than 75 percent of the _____ harvested in the United States.
17. Salt marshes are a mosaic of snaking channels called _____. [two words]
18. Most coastal plain estuaries in North America were formed at the end of the last _____. [two words]
20. _____ is a spongy matrix of live roots, decomposing organic material, and soil that helps filter pollutants out of the water.
21. Salt _____ are shallow depressions that contain very high concentrations of salt.
22. _____ are steep-walled river valleys created by advancing glaciers that later became flooded with seawater as the glaciers retreated.
24. Of the 32 largest cities in the world, 22 are located on ____ _____.
25. A protected area of calm water between the coast and a barrier island is called a _____.
28. Estuaries provide critical _____ for many birds, fish, amphibians, insects, and other wildlife.
29. Waters whose salt content is between that of freshwater and that of seawater are called _____.

Crossword Puzzle 2:

Across

2. Plants and animals that can tolerate a wide range of salinities are called _____.
3. Salt marshes are covered with salt-tolerant plants called _____.
7. In estuaries, salinity levels are generally _____ near the mouth of a river where the ocean water enters.
9. _____ is related to the amount of sediment and other solids suspended in water.
11. During low tides, oysters close up their shells, stop feeding, and switch to _____ respiration.
13. As water temperature increases, the amount of oxygen that can dissolve in the water _____.
17. As they develop, blue crabs eventually return to the estuary as young crabs called _____.
19. _____ trees grow at tropical and subtropical latitudes, and can grow in anoxic soils where slow moving waters allow fine sediments to accumulate.
20. Plants and animals that can tolerate only slight changes in salinity are called _____.
21. _____ is a partnership program between NOAA and U.S. coastal states that protects more than one million acres of estuarine land and water.
22. Scientists can determine the density of phytoplankton and the amount of primary productivity by measuring _____.
24. _____ is one of the main components of peat and dominates the low marsh all the way up to the estuary's edge. [two words]
25. The amount of _____ in an estuary's waters is the major factor that determines the type and abundance of organisms that can live there. [two words]
27. Oxygen enters the water through two natural processes: diffusion from the atmosphere, and _____.
28. Bacteria, fungi, and other decomposer organisms reduce DO levels in estuaries because they consume oxygen while breaking down _____. [two words]
29. The amount of oxygen that can dissolve in water _____ as salinity decreases.
30. The chemical components in seawater resist large changes to _____.
31. Burrowing organisms such as clams, mussels, oysters, fiddler

crabs, sand shrimp, and blood worms are typical of _____.

32. _____ is a process through which toxic substances can accumulate in the tissues of organisms that consume these substances.
33. The _____ colonizes the seaward side of mangals. [two words]
34. Many species of mangrove trees have aerial roots called _____ that take up oxygen from the air for the roots.
35. The zone where white mangrove and buttonwood trees grow is almost never _____.

Down

1. Non-native species are often introduced to estuaries in the _____ of ships. [two words]
4. Some toxic substances become attached to _____ that flow down rivers and get deposited in estuaries.
5. Many mangals can be recognized by their dense tangle of _____ that make the trees appear to be standing on stilts above the water. [two words]
6. A common natural disturbance to estuaries in non-tropical regions is _____. [two words]
8. _____ are disease-causing organisms.
10. _____ are plants and animals that have found their way into areas outside their normal range.
12. _____ pollution is the single largest pollution problem effecting coastal waters of the United States.
14. In most estuaries, the largest contributor of bacteria and viruses is probably _____. [three words]
15. A natural disturbance in salt marshes caused by the burial of vegetation by rafts of dead floating plant material, called _____.
16. Mangrove seeds that begin growing while still attached to the parent plant are called _____.
18. It requires a lot of _____ to adapt to constantly changing salinities.
20. The health of every National Estuary Reserve is continuously monitored by the _____.
23. Blue crab larvae called _____ require water with a salinity over 30 ppt for optimal development.
26. _____ is a type of pollution in which excess nutrients stimulate an explosive growth of algae which depletes the water of oxygen when the algae die and are eaten by bacteria.

ESTUARY SELF TEST

Fill-in-the-Blank

1. An _____ is a partially enclosed body of water and its adjacent habitats where saltwater from the ocean mixes with freshwater from rivers or streams.

2. Waters whose salt content is between that of freshwater and that of seawater are called _____.

3. Of the 32 largest cities in the world, 22 are located on _____.

4. In the ocean the concentration of salts, or _____, averages about 35 parts per thousand.

5. The salinity of estuarine water is _____ from one day to the next.

6. _____ are a major influence on many estuaries.

7. Most areas of the earth experience _____ high and low tides each day.

8. Tides at broad mudflats might appear to be _____ than tides at the end of a long, narrow inlet.

9. Every estuary is _____.

10. Estuaries are typically classified based on how saltwater and freshwater mix in the estuary and on their _____.

11. Estuaries formed by rivers or streams entering massive lakes are called _____ estuaries.

12. Estuaries are often called _____ of the sea.

13. Estuaries filter out _____ from rivers and streams before they flow into the oceans.

14. Estuaries provide critical _____ for many birds, fish, amphibians, insects, and other wildlife.

15. Estuaries provide habitat for more than 75 percent of the _____ harvested in the United States.

16. _____ are fundamental life support processes upon which all organisms depend. [two words]

17. _____ is a spongy matrix of live roots, decomposing organic material, and soil that helps filter pollutants out of the water.

18. One reason that estuaries are so productive is that the water filtering through them brings in _____ from the surrounding watershed.

19. The entire land area that drains into a particular body of water, like a lake, river or estuary is called a drainage basin or _____.

20. Estuaries are some of the most fertile ecosystems on earth, yet they may also be one of the most _____.

21. Estuaries and their surrounding wetlands act as _____ that stabilize shorelines and protect coastal areas from floods, storm surges, and excessive erosion.

22. The _____ determines the rate of freshwater that flows into an estuary from rivers and streams. [two words]

23. _____ estuaries are formed when rising sea levels flood existing river valleys. [two words]

24. _____ estuaries are characterized by barrier beaches or islands that form parallel to the coastline and separate the estuary from the ocean. [two words]

25. _____ beaches and islands are formed by the accumulation of sand or sediments deposited by ocean waves.

26. A _____ is characterized by large flat fan-shaped deposits of sediment at the mouth of a river.

27. _____ estuaries are formed when the earth's tectonic plates run into or fold-up underneath each other.

28. _____ are steep-walled river valleys created by advancing glaciers that later became flooded with seawater as the glaciers retreated.

29. Most coastal plain estuaries in North America were formed at the end of the last_____. [two words]

30. A protected area of calm water between the coast and a barrier island is called a _____.

31. Bar-built estuaries and deltas both have large deposits of _____.

32. The first stage in the formation of a tectonic estuary typically occurs during _____.

33. _____ tend to have a moderately high input of freshwater, but very little inflow of seawater.

34. When a sill prevents deep waters in an estuary from mixing with deep waters of the sea, poor water exchange causes _____ (low oxygen) water to build up on the bottom of the estuary.

35. Estuaries with a sill are found in areas that were once covered with _____.

36. _____ create saltwater currents that move seawater into estuaries. [two words]

37. The daily mixing of freshwater and saltwater in estuaries leads to variable and dynamic chemical conditions, especially _____.

38. Because freshwater flowing into the estuary is less _____ ____ than water from the ocean, it often floats on top of the heavier seawater.

39. The difference between the average low tide and the average high tide is the _____. [two words]

40. _____ are areas in water that have equal salt concentrations.

41. The shape of the isohalines indicates the amount of _____ that is occurring, and may provide clues about the estuary's geology.

42. _____ estuaries occur when a rapidly-flowing river discharges into the ocean where tidal currents are weak. [two words]

43. In _____ estuaries, saltwater and freshwater mix at all depths. [two words]

44. A _____ estuary occurs when river flow is low and tidally generated currents are moderate to strong. [two words]

45. Freshwater estuaries are driven by _____.

46. Salt marshes are a mosaic of snaking channels called _____.

47. Salt _____ are shallow depressions that contain very high concentrations of salt.

48. Burrowing organisms such as clams, mussels, oysters, fiddler crabs, sand shrimp, and blood worms are typical of _____.

49. Salt marshes are covered with salt-tolerant plants called _____.

50. _____ is one of the main components of peat and dominates the low marsh all the way up to the estuary's edge. [two words]

51. _____ trees grow at tropical and subtropical latitudes, and can grow in anoxic soils where slow moving waters allow fine sediments to accumulate.

52. Many mangals can be recognized by their dense tangle of _____ that make the trees appear to be standing on stilts above the water. [two words]

53. The _____ colonizes the seaward side of mangals. [two words]

54. The zones where white mangrove and buttonwood trees grow are almost never _____.

55. Plants and animals living in estuaries must be able to respond quickly to drastic changes in _____.

56. Plants and animals that can tolerate only slight changes in salinity are called _____.

57. Plants and animals that can tolerate a wide range of salinities are called _____.

58. It requires a lot of _____ to adapt to constantly changing salinities.

59. Many species of mangrove trees have aerial roots called _____ that take up oxygen from the air for the roots.

60. Mangrove seeds that begin growing while still attached to the parent plant are called _____.

61. During low tides, oysters close up their shells, stop feeding, and switch to _____ respiration.

62. Blue crab larvae called _____ require water with a salinity over 30 ppt for optimal development.

63. As they develop, blue crabs eventually return to the estuary as young crabs called _____.

64. _____ disturbances are caused by humans.

65. Large _____ are especially destructive to estuaries.

66. A common natural disturbance to estuaries in non-tropical regions is _____. [two words]

67. A natural disturbance in salt marshes caused by the burial of vegetation by rafts of dead floating plant material, is called _____.

68. The greatest human-caused threat to estuaries is their large-scale _____.

69. _____ is probably the most important threat to water quality in estuaries.

70. _____ is a process through which toxic substances can accumulate in the tissues of organisms that consume these substances.

71. Some toxic substances become attached to _____ that flow down rivers and get deposited in estuaries.

72. _____ is a type of pollution in which excess nutrients stimulate an explosive growth of algae which depletes the water of oxygen when the algae die and are eaten by bacteria.

73. _____ pollution is the single largest pollution problem affecting coastal waters of the United States.

74. _____ are disease-causing organisms.

75. In most estuaries, the largest contributor of bacteria and viruses is probably _____. [three words]

76. _____ are plants and animals that have found their way into areas outside their normal range.

77. Non-native species are often introduced to estuaries in the _____ water of ships.

78. _____ is a partnership program between NOAA and U.S. coastal states that protects more than one million acres of estuarine land and water.

79. The health of every National Estuary Reserve is continuously monitored by the _____.

80. As water temperature increases, the amount of oxygen that can dissolve in the water _____.

81. In estuaries, salinity levels are generally _____ near the mouth of a river where the ocean water enters.

82. The amount of oxygen that can dissolve in water _____ as salinity decreases.

83. The amount of _____ in an estuary's waters is the major factor that determines the type and abundance of organisms that can live there. [two words]

84. Oxygen enters the water through two natural processes: diffusion from the atmosphere, and _____.

85. Bacteria, fungi, and other decomposer organisms reduce DO levels in estuaries because they consume oxygen while breaking down _____. [two words]

86. _____ is related to the amount of sediment and other solids suspended in water.

87. The chemical components in seawater resist large changes to _____.

88. Scientists can determine the density of phytoplankton and the amount of primary productivity by measuring _____.

ESTUARY SELF TEST

Word Bank

WORD BANK

stenohaline
euryhaline
energy
pneumatophores
propagules
anaerobic
zoea
megalope
anthropogenic
storms
winter ice
anoxic
glaciers
high tides
bar built
barrier
delta
tectonic
smaller
unique
geology
estuary
brackish
estuaries
salinity
variable
tides
two
freshwater
nurseries
pollutants
habitat
fish
ecosystem services
ice age
decreases
lagoons
sediment
earthquakes
fjords
tidal creeks
pannes
mudflats
nutrients
watershed
SWMP
polluted
buffers
coastal elevation
coastal plain
halophytes
smooth cordgrass
mangrove
prop roots
salinity
dense
tidal range
isohalines
highest
mixing
salt wedge
slightly stratified
vertically-mixed
storms
peat
red mangrove
flooded
salinity
wrack
conversion
pollution
biomagnification
sediments
eutrophication
nutrient
pathogens
combined sewage overflows
invasives
NERRS
increases
dissolved oxygen
photosynthesis
organic matter
turbidity
pH
chlorophyll

ESTUARY SELF TEST

Crossword No. 1 Answer Key

Across

4. A **vertically mixed** estuary occurs when river flow is low and tidally generated currents are moderate to strong. [two words]
7. Estuaries and their surrounding wetlands act as **buffers** that stabilize shorelines and protect coastal areas from floods, storm surges, and excessive erosion.
9. Estuaries with a sill are found in areas that were once covered with **glaciers.**
13. **Salt wedge** estuaries occur when a rapidly-flowing river discharges into the ocean where tidal currents are weak. [two words]
14. Estuaries filter out **pollutants** from rivers and streams before they flow into the oceans
15. One reason that estuaries are so productive is that the water filtering through them brings in **nutrients** from the surrounding watershed.
17. **Tectonic** estuaries are formed when the earth's tectonic plates run into or fold-up underneath each other
19. **Tides** are a major influence on many estuaries.
22. Estuaries formed by rivers or streams entering massive lakes are called **freshwater** estuaries.
23. A **delta** is characterized by large flat fan-shaped deposits of sediment at the mouth of a river.
26. An **estuary** is a partially enclosed body of water and its adjacent habitats where saltwater from the ocean mixes with freshwater from rivers or streams.
27. **Isohalines** are areas in water that have equal salt concentrations.
30. **Coastal plain** estuaries are formed when rising sea levels flood existing river valleys. [two words]
31. **Barrier** beaches and islands are formed by the accumulation of sand or sediments deposited by ocean waves.
32. **Bar built** estuaries are characterized by barrier beaches or islands that form parallel to the coastline and separate the estuary from the ocean. [two words]
33. In the ocean the concentration of salts, or **salinity** averages about 35 parts per thousand

Down

1. **Ecosystem services** are fundamental life support processes upon which all organisms depend. [two words]
2. Estuaries are often called **nurseries** of the sea.
3. Estuaries are typically classified based on how saltwater and freshwater mix in the estuary and on their **geology**.
5. Because freshwater flowing into the estuary is less **dense** than water from the ocean, it often floats on top of the heavier seawater.
6. Tides at broad mudflats might appear to be **smaller** than tides at the end of a long, narrow inlet.
8. The first stage in the formation of a tectonic estuary typically occurs during **earthquakes**.
10. The **coastal elevation** determines the rate of freshwater that flows into an estuary from rivers and streams. [two words]
11. When a sill prevents deep waters in an estuary from mixing with deep waters of the sea, poor water exchange causes **anoxic** (low oxygen) water to build up on the bottom of the estuary.
12. The shape of the isohalines indicates the amount of **mixing** that is occurring, and may provide clues about the estuary's geology.
16. Estuaries provide habitat for more than 75 percent of the **fish** harvested in the United States.
17. Salt marshes are a mosaic of snaking channels called **tidal creeks**. [two words]
18. Most coastal plain estuaries in North America were formed at the end of the last **ice age**.[two words]
20. **Peat** is a spongy matrix of live roots, decomposing organic material, and soil that helps filter pollutants out of the water.
21. Salt **pannes** are shallow depressions that contain very high concentrations of salt.
22. **Fjords** are steep-walled river valleys created by advancing glaciers that later became flooded with seawater as the glaciers retreated.
24. Of the 32 largest cities in the world, 22 are located on **estuaries**.
25. A protected area of calm water between the coast and a barrier island is called a **lagoon**.

28. Estuaries provide critical **habitat** for many birds, fish, amphibians, insects, and other wildlife.
29. Waters whose salt content is between that of freshwater and that of seawater are called **brackish**.

Crossword No. 2 Answer Key

Across

2. Plants and animals that can tolerate a wide range of salinities are called **euryhaline**.
3. Salt marshes are covered with salt-tolerant plants called **halophytes**.
7. In estuaries, salinity levels are generally **highest** near the mouth of a river where the ocean water enters.
9. **Turbidity** is related to the amount of sediment and other solids suspended in water.
11. During low tides, oysters close up their shells, stop feeding, and switch to **anaerobic** respiration.
13. As water temperature increases, the amount of oxygen that can dissolve in the water **decreases**.
17. As they develop, blue crabs eventually return to the estuary as young crabs called **megalope**.
19. **Mangrove** trees grow at tropical and subtropical latitudes, and can grow in anoxic soils where slow moving waters allow fine sediments to accumulate.
20. Plants and animals that can tolerate only slight changes in salinity are called **stenohaline**.
21. **NERRS** is a partnership program between NOAA and U.S. coastal states that protects more than one million acres of estuarine land and water.
22. Scientists can determine the density of phytoplankton and the amount of primary productivity by measuring **chlorophyll**.
24. **Smooth cordgrass** is one of the main components of peat and dominates the low marsh all the way up to the estuary's edge. [two words]
25. The amount of **dissolved oxygen** in an estuary's waters is the major factor that determines the type and abundance of organisms that can live there. [two words]
27. Oxygen enters the water through two natural processes: diffusion from the atmosphere, and **photosynthesis**.

28. Bacteria, fungi, and other decomposer organisms reduce DO levels in estuaries because they consume oxygen while breaking down **organic matter.** [two words]
29. The amount of oxygen that can dissolve in water **increases** as salinity decreases.
30. The chemical components in seawater resist large changes to **pH.**
31. Burrowing organisms such as clams, mussels, oysters, fiddler crabs, sand shrimp, and blood worms are typical of **mudflats.**
32. **Biomagnification** is a process through which toxic substances can accumulate in the tissues of organisms that consume these substances.
33. The **red mangrove** colonizes the seaward side of mangals. [two words]
34. Many species of mangrove trees have aerial roots called **pneumatophores** that take up oxygen from the air for the roots.
35. The zone where white mangrove and buttonwood trees grow is almost never **flooded.**

Down

1. Non-native species are often introduced to estuaries in the **ballast** water of ships.
4. Some toxic substances become attached to **sediments** that flow down rivers and get deposited in estuaries.
5. Many mangals can be recognized by their dense tangle of **prop roots** that make the trees appear to be standing on stilts above the water. [two words]
6. A common natural disturbance to estuaries in non-tropical regions is **winter ice.**[two words]
8. **Pathogens** are disease-causing organisms.
10. **Invasives** are plants and animals that have found their way into areas outside their normal range.
12. **Nutrient** pollution is the single largest pollution problem effecting coastal waters of the United States.
14. In most estuaries, the largest contributor of bacteria and viruses is probably **combined sewage overflows.** [three words]
15. A natural disturbance in salt marshes caused by the burial of vegetation by rafts of dead floating plant material, called **wrack.**

16. Mangrove seeds that begin growing while still attached to the parent plant are called **propagules**.
18. It requires a lot of **energy** to adapt to constantly changing salinities.
20. The health of every National Estuary Reserve is continuously monitored by the **SWMP**.
23. Blue crab larvae called **zoea** require water with a salinity over 30 ppt for optimal development.
26. **Eutrophication** is a type of pollution in which excess nutrients stimulate an explosive growth of algae which depletes the water of oxygen when the algae die and are eaten by bacteria.

ESTUARY SELF TEST

Fill-in-the-Blank Answer Key

1. An **estuary** is a partially enclosed body of water and its adjacent habitats where saltwater from the ocean mixes with freshwater from rivers or streams.
2. Waters whose salt content is between that of freshwater and that of seawater are called **brackish**.
3. Of the 32 largest cities in the world, 22 are located on **estuaries**.
4. In the ocean the concentration of salts, or **salinity** averages about 35 parts per thousand.
5. The salinity of estuarine water is **variable** from one day to the next.
6. **Tides** are a major influence on many estuaries.
7. Most areas of the earth experience **two** high and low tides each day.
8. Tides at broad mudflats might appear to be **smaller** than tides at the end of a long, narrow inlet.
9. Every estuary is **unique**.
10. Estuaries are typically classified based on how saltwater and freshwater mix in the estuary and on their **geology**.
11. Estuaries formed by rivers or streams entering massive lakes are called **freshwater** estuaries.
12. Estuaries are often called **nurseries** of the sea.
13. Estuaries filter out **pollutants** from rivers and streams before they flow into the oceans.
14. Estuaries provide critical **habitat** for many birds, fish, amphibians, insects, and other wildlife.
15. Estuaries provide habitat for more than 75 percent of the **fish** harvested in the United States.
16. **Ecosystem services** are fundamental life support processes upon which all organisms depend. [two words]
17. **Peat** is a spongy matrix of live roots, decomposing organic material, and soil that helps filter pollutants out of the water.
18. One reason that estuaries are so productive is that the water filtering through them brings in **nutrients** from the surrounding watershed.

19. The entire land area that drains into a particular body of water, like a lake, river or estuary is called a drainage basin or **watershed**.
20. Estuaries are some of the most fertile ecosystems on earth, yet they may also be one of the most **polluted**.
21. Estuaries and their surrounding wetlands act as **buffers** that stabilize shorelines and protect coastal areas from floods, storm surges, and excessive erosion.
22. The **coastal elevation** determines the rate of freshwater that flows into an estuary from rivers and streams. [two words]
23. **Coastal plain** estuaries are formed when rising sea levels flood existing river valleys. [two words]
24. **Bar built** estuaries are characterized by barrier beaches or islands that form parallel to the coastline and separate the estuary from the ocean. [two words]
25. **Barrier** beaches and islands are formed by the accumulation of sand or sediments deposited by ocean waves.
26. A **delta** is characterized by large flat fan-shaped deposits of sediment at the mouth of a river.
27. **Tectonic** estuaries are formed when the earth's tectonic plates run into or fold-up underneath each other
28. **Fjords** are steep-walled river valleys created by advancing glaciers that later became flooded with seawater as the glaciers retreated.
29. Most coastal plain estuaries in North America were formed at the end of the last **ice age**.[two words]
30. A protected area of calm water between the coast and a barrier island is called a **lagoon**.
31. Bar-built estuaries and deltas both have large deposits of **sediment**.
32. The first stage in the formation of a tectonic estuary typically occurs during **earthquakes**.
33. **Fjords** tend to have a moderately high input of freshwater, but very little inflow of seawater.
34. When a sill prevents deep waters in an estuary from mixing with deep waters of the sea, poor water exchange causes **anoxic** (low oxygen) water to build up on the bottom of the estuary.
35. Estuaries with a sill are found in areas that were once covered with **glaciers**.

36. **High tides** create saltwater currents that move seawater into estuaries. [two words]
37. The daily mixing of freshwater and saltwater in estuaries leads to variable and dynamic chemical conditions, especially **salinity**.
38. Because freshwater flowing into the estuary is less **dense** than water from the ocean, it often floats on top of the heavier seawater.
39. The difference between the average low tide and the average high tide is the **tidal range.** [two words]
40. **Isohalines** are areas in water that have equal salt concentrations.
41. The shape of the isohalines indicates the amount of **mixing** that is occurring, and may provide clues about the estuary's geology.
42. **Salt wedge** estuaries occur when a rapidly-flowing river discharges into the ocean where tidal currents are weak. [two words]
43. In **slightly stratified** estuaries, saltwater and freshwater mix at all depths. [two words]
44. A **vertically mixed** estuary occurs when river flow is low and tidally generated currents are moderate to strong.
45. Freshwater estuaries are driven by **storms.**
46. Salt marshes are a mosaic of snaking channels called **tidal creeks.**
47. Salt **pannes** are shallow depressions that contain very high concentrations of salt.
48. Burrowing organisms such as clams, mussels, oysters, fiddler crabs, sand shrimp, and blood worms are typical of **mudflats.**
49. Salt marshes are covered with salt-tolerant plants called **halophytes.**
50. **Smooth cordgrass** is one of the main components of peat and dominates the low marsh all the way up to the estuary's edge. [two words]
51. **Mangrove** trees grow at tropical and subtropical latitudes, and can grow in anoxic soils where slow moving waters allow fine sediments to accumulate.
52. Many mangals can be recognized by their dense tangle of **prop roots** that make the trees appear to be standing on stilts above the water. [two words]

53. The **red mangrove** colonizes the seaward side of mangals. [two words]
54. The zone where white mangrove and buttonwood trees grow are almost never **flooded**.
55. Plants and animals living in estuaries must be able to respond quickly to drastic changes in **salinity**.
56. Plants and animals that can tolerate only slight changes in salinity are called **stenohaline**.
57. Plants and animals that can tolerate a wide range of salinities are called **euryhaline**.
58. It requires a lot of **energy** to adapt to constantly changing salinities.
59. Many species of mangrove trees have aerial roots called **pneumatophores** that take up oxygen from the air for the roots.
60. Mangrove seeds that begin growing while still attached to the parent plant are called **propagules**.
61. During low tides, oysters close up their shells, stop feeding, and switch to **anaerobic** respiration.
62. Blue crab larvae called **zoea** require water with a salinity over 30 ppt for optimal development.
63. As they develop, blue crabs eventually return to the estuary as young crabs called **megalope**.
64. **Anthropogenic** disturbances are caused by humans.
65. Large **storms** are especially destructive to estuaries
66. A common natural disturbance to estuaries in non-tropical regions is **winter ice**. [two words]
67. A natural disturbance in salt marshes caused by the burial of vegetation by rafts of dead floating plant material, called **wrack**.
68. The greatest human-caused threat to estuaries is their large-scale **conversion**.
69. Pollution is probably the most important threat to water quality in estuaries.
70. **Biomagnification** is a process through which toxic substances can accumulate in the tissues of organisms that consume these substances.
71. Some toxic substances become attached to **sediments** that flow down rivers and get deposited in estuaries.

72. **Eutrophication** is a type of pollution in which excess nutrients stimulate an explosive growth of algae which depletes the water of oxygen when the algae die and are eaten by bacteria.
73. **Nutrient** pollution is the single largest pollution problem effecting coastal waters of the United States.
74. **Pathogens** are disease-causing organisms.
75. In most estuaries, the largest contributor of bacteria and viruses is probably **combined sewage overflows.** [three words]
76. **Invasives** are plants and animals that have found their way into areas outside their normal range.
77. Non-native species are often introduced to estuaries in the **ballast** water of ships.
78. **NERRS** is a partnership program between NOAA and U.S. coastal states that protects more than one million acres of estuarine land and water.
79. The health of every National Estuary Reserve is continuously monitored by the **SWMP.**
80. As water temperature increases, the amount of oxygen that can dissolve in the water **decreases.**
81. In estuaries, salinity levels are generally **higher** near the mouth of a river where the ocean water enters.
82. The amount of oxygen that can dissolve in water **increases** as salinity decreases.
83. The amount of **dissolved oxygen** in an estuary's waters is the major factor that determines the type and abundance of organisms that can live there. [two words]
84. Oxygen enters the water through two natural processes: diffusion from the atmosphere, and **photosynthesis.**
85. Bacteria, fungi, and other decomposer organisms reduce DO (dissolved oxygen) levels in estuaries because they consume oxygen while breaking down **organic matter** [two words]
86. **Turbidity** is related to the amount of sediment and other solids suspended in water.
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